Critical Materials Institute

AN ENERGY INNOVATION HUB

One Year In, looking back, and looking ahead

Alex King

Values

We Listen

We are driven by the needs of technology and our best information comes from our industry partners.

We Are Safe

We conduct all of our work in a manner that protects our workers, the public and the environment.

We Collaborate

We bring together the best available expertise to solve the problems at hand.

We Respect

We treat each other well and value the contributions of all.

We Move Fast

We strive to reach key decision points as early as possible.

We Are Agile

We respond quickly to changing conditions and new information.

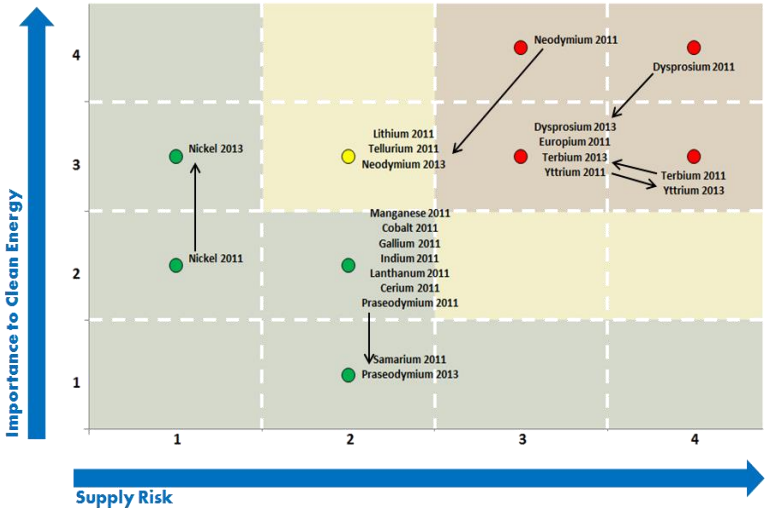
We Are Responsible

We use taxpayers' and industry's resources appropriately.

We Deliver

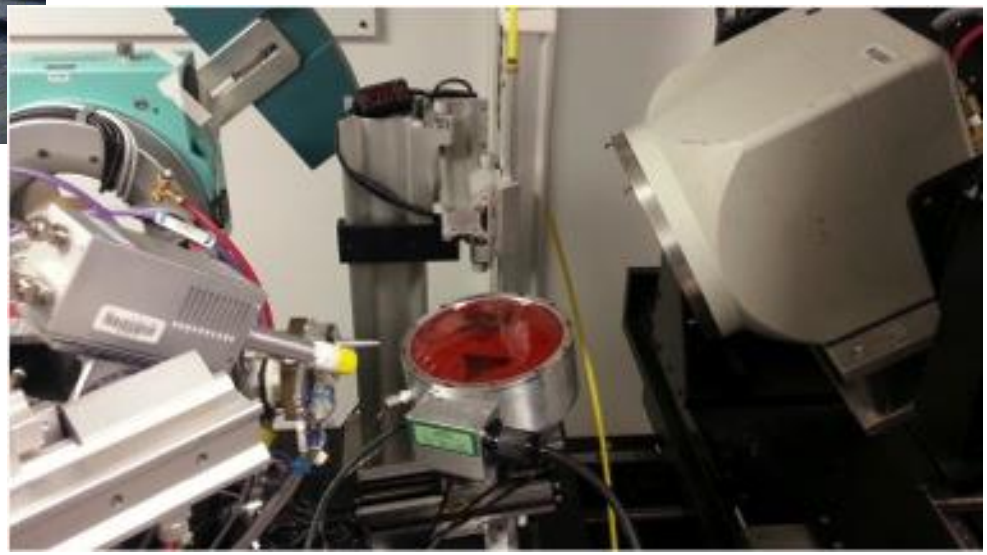
Facilities and capabilities

Improved capabilities for assessing "what is critical"? (CSM)



Rapid analysis of combinatoric array samples (SSRL, in conjunction with JCAP & JCESR)

Bulk combinatoric materials synthesis facility (Ames)



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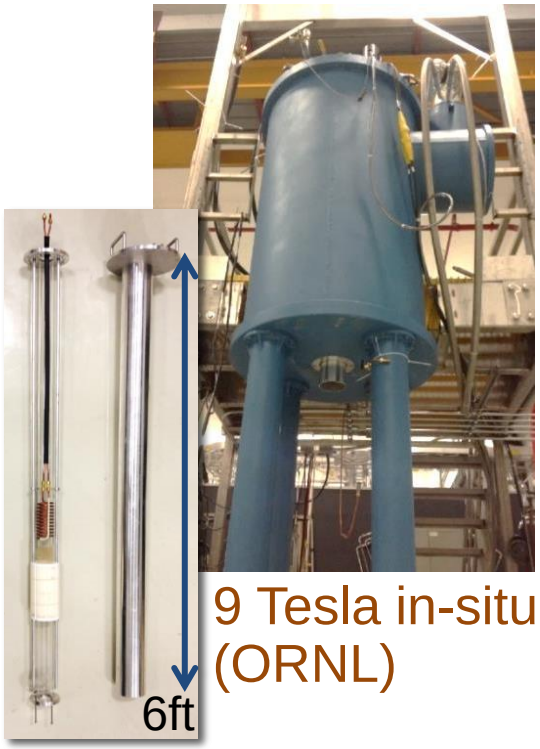
Facilities and capabilities

Pilot-scale separations test-bed facility (INL)

Filtration test-bed facility (INL)

Facilities and capabilities

Ferromagnetic materials characterization facility (Ames)



9 Tesla in-situ DSC / DTA facility (ORNL)

9 Tesla thermomagnetic processing facility (ORNL)

Industrial Membership Program

- New program is attracting new industrial partners and collaborators

Invention disclosures

- Extraction of rare earth elements from phosphoric acid streams
- Extraction of rare earths from fly ash
- Recovery of neodymium from neodymium iron boride magnets
- Membrane solvent extraction for rare earth separations
- Selective composite membranes for lithium extraction from geothermal brines
- Methods of separating lithium-chloride from geothermal brine solutions
- Recovery of Dy-enriched Fe alloy from magnet scrap alloy via selective separation of rare earth elements
- Aluminum nitride phosphors for fluorescent lighting
- Novel surface coatings to improve the functional properties of permanent magnets

Invention disclosures – *page 2*

- Additive manufacturing of bonded permanent magnets using a novel polymer matrix
- Ceria-based catalyst for selective phenol hydrogenation under mild reaction conditions
- Recycling and conversion of samarium cobalt magnet waste into useful magnet
- Catalysts for styrene production
- Recycle of Fe Nd B machine swarf and magnets
- Task specific ionic liquids extractive metallurgy or rare earth minerals
- Separation of neodymium from praseodymium
- High throughput cost effective rare earth magnets recycling system

What next? The agenda for the coming year

1. The establishment of CMI's experimental tools will be completed, providing unique capabilities to CMI's members, partners and affiliates.

2. New CMI computational tools will be implemented.

3. CMI's analysis frameworks and databases will be populated with data.

4. All of CMI's projects will be roadmapped to identify critical project steps, decision points, and connections to anticipated technology developments.

5. Materials and processes selected for detailed investigation studied in depth and will reach key "go/no-go" decision points.

6. New industrial partners and affiliates will be enrolled in CMI, doubling its interactions with the corporate sector.

What next? The agenda for the coming year

7. CMI will establish research collaborations with other entities that help to accelerate the achievement of its goals, leveraging other investments and preventing duplication and overlap of effort.

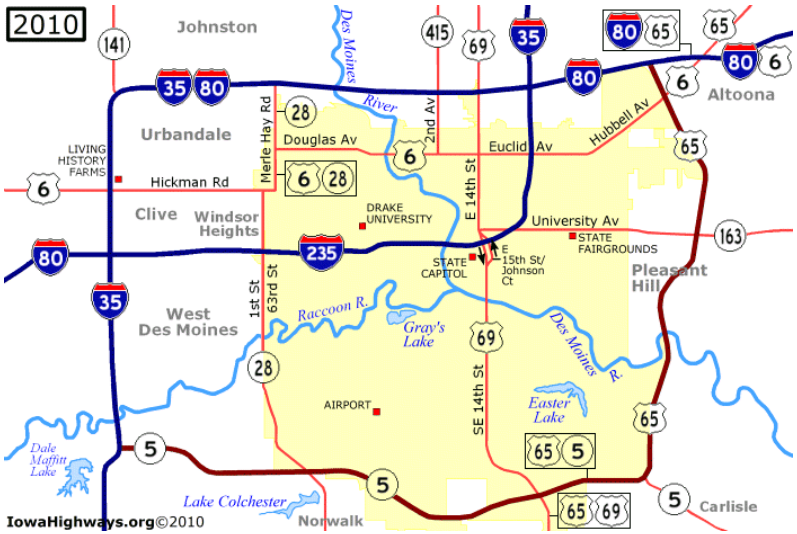
8. CMI will evaluate the needs for expertise and training among U.S. corporations that are affected by materials criticality, and will develop strategies to meet these needs.

9. CMI will provide information and expert advice to assist policy makers and implementers in making scientifically sound, technically viable decisions.

10. CMI will start a small number of new projects in emerging opportunity areas, in close collaboration with its industry partners.

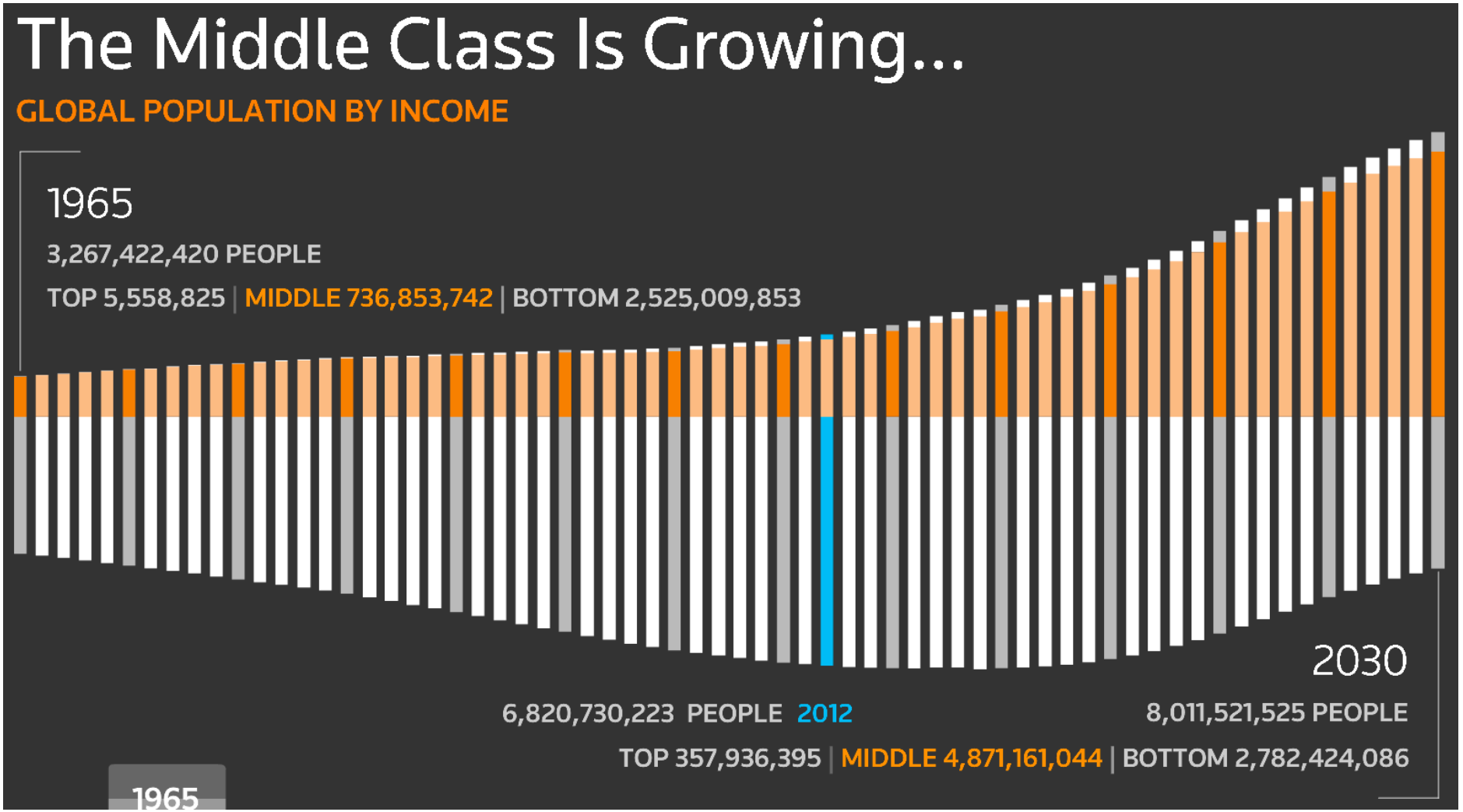
11. CMI will draft and implement a strategic plan for its operations, including provisions for a transition to post-award self-sustainability.

Where next? Roadmaps, milestones and intersections



- The roadmap tells you where you are going
- The mile markers tell you how fast you are getting there
- The intersections represent key decision points

Global Scale Roadmaps



http://www.reuters.com/middle-class-infographic

Technology is growing more complex

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cp		Fl		Lv		

Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

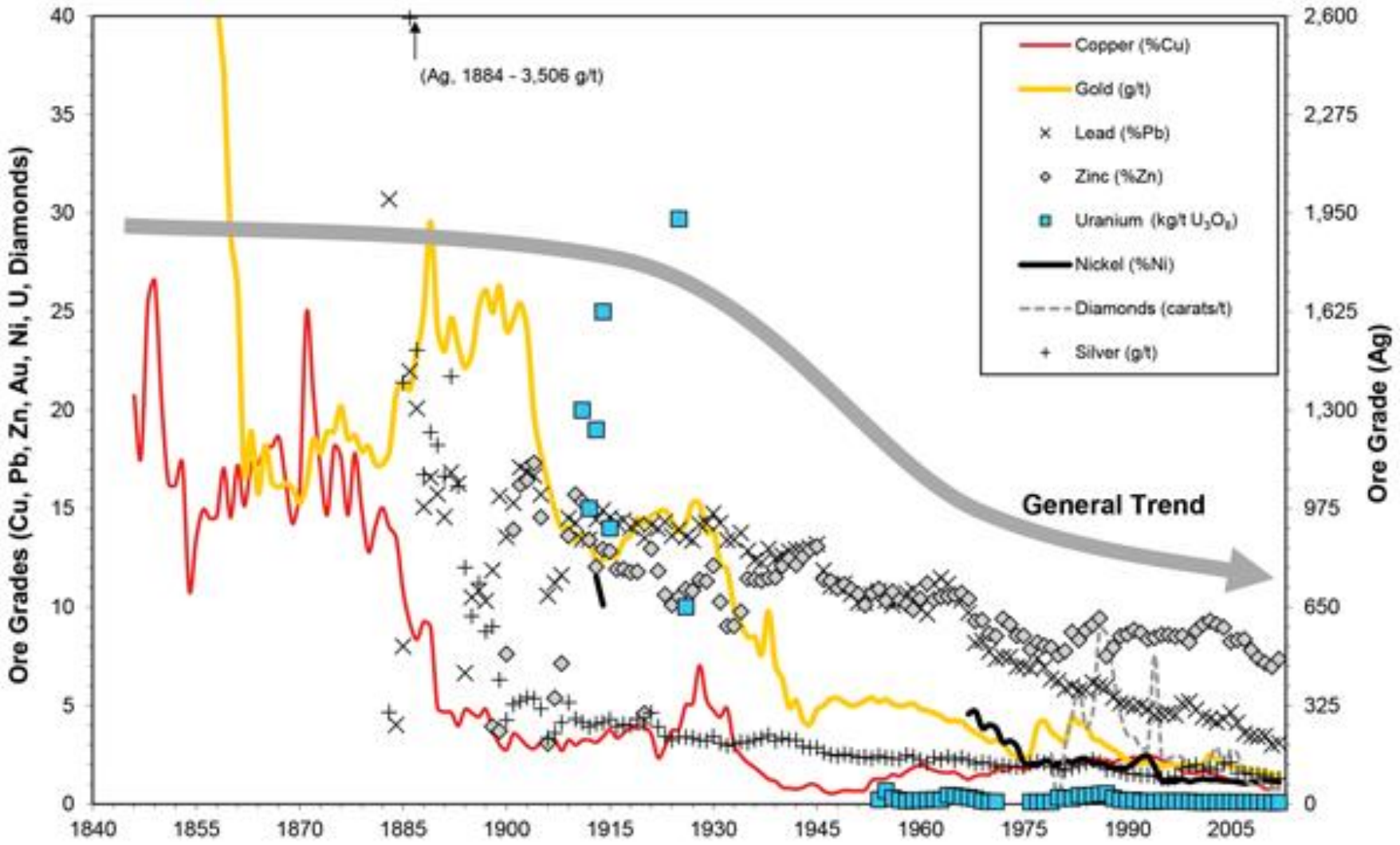
~30 elements

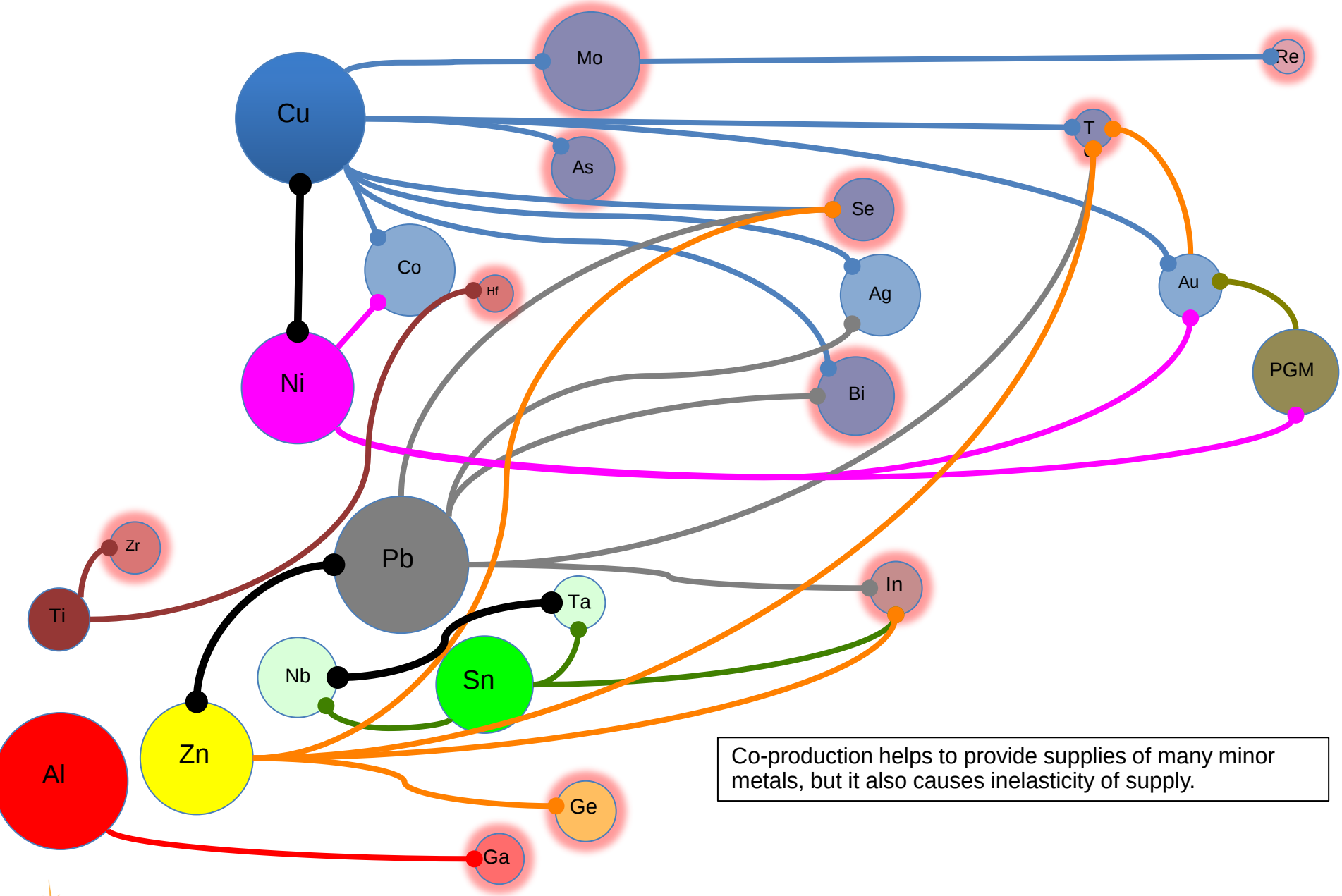
H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Cp		Fl		Lv		

Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

~75 elements

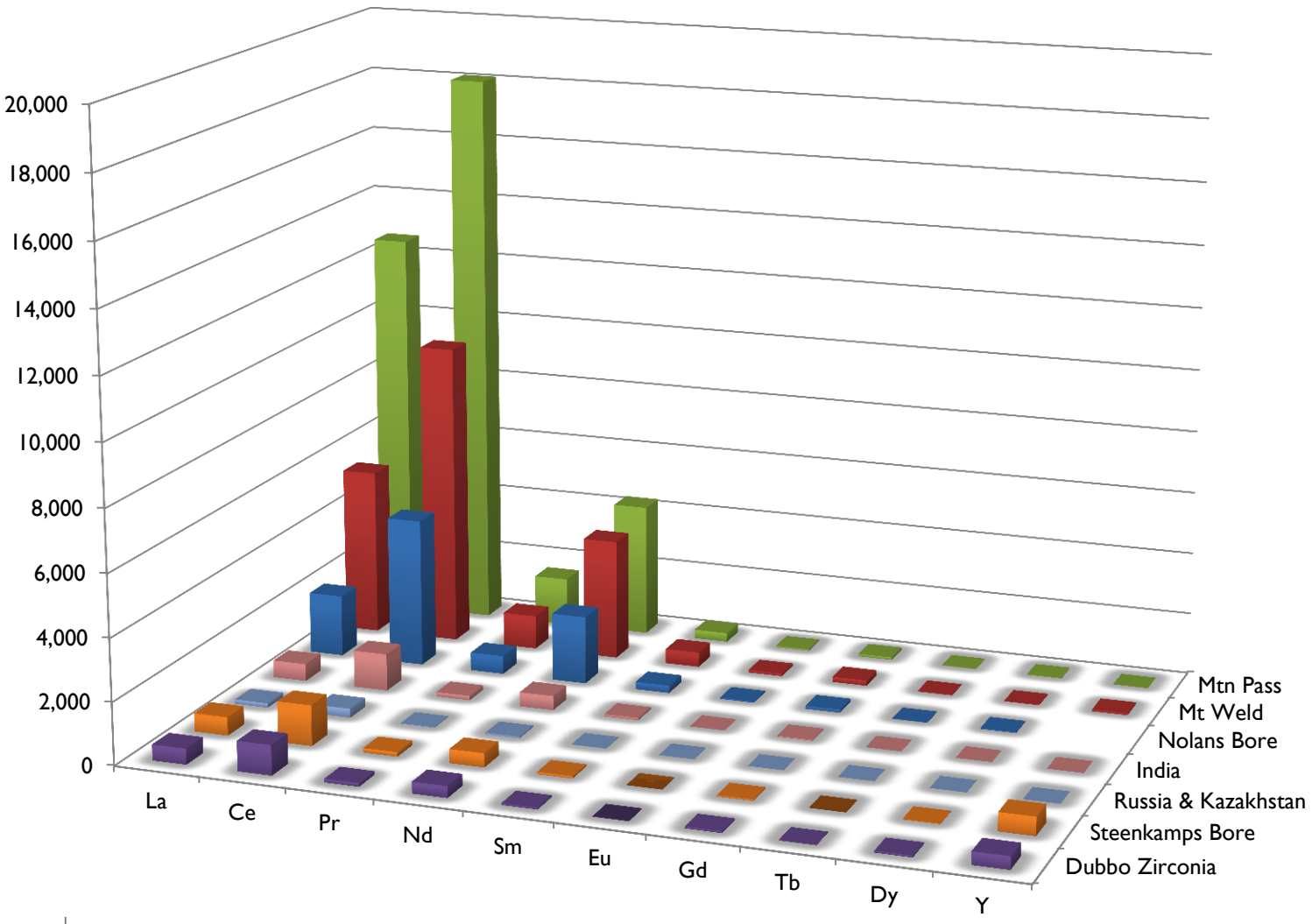
Ore grades are declining





Co-production helps to provide supplies of many minor metals, but it also causes inelasticity of supply.

Rare earths are archetypally co-produced



The opposite of a critical material

- Stuff you really need to get rid of, if only you could
  - Lead
  - Mercury
  - Thorium
  - Uranium

  } Regulatory (and hence also economic) issues

  - Cerium
  - Lanthanum
  - …

  } "Only" economic issues

- We call these *ANA*CRITICAL materials
  - As with critical materials, the list might vary depending on who, when or where you ask, and the grand challenges are also quite similar

Interdependence

- Technologies drive material choices
  - Thinner interconnects in integrated circuits cause increasing resistance and more electromigration failures:
    Switch from Al to Cu

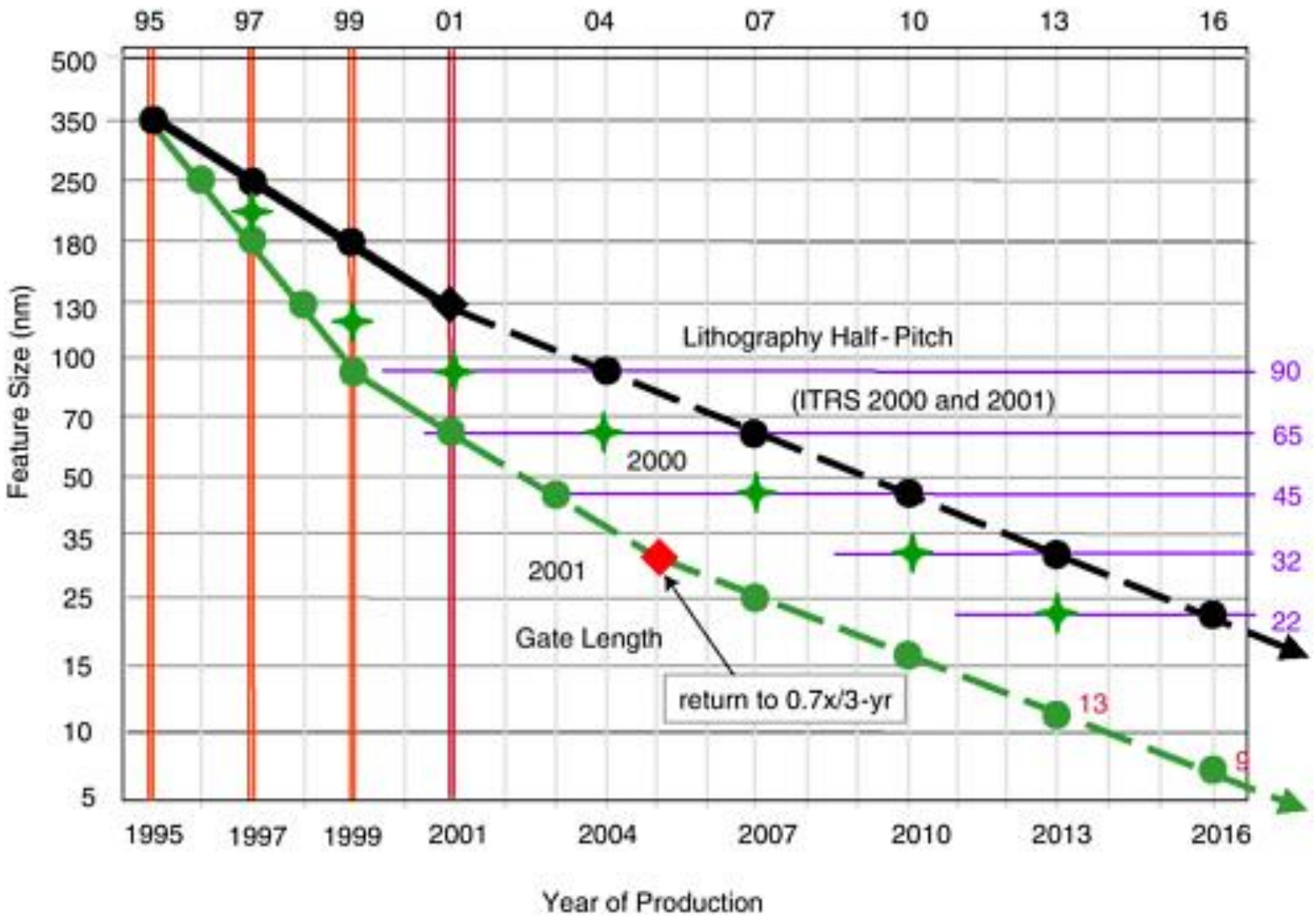
- Materials drive technology choices
  - Rare earth supplies are uncertain:
    Make gearbox-based wind turbines
    Use induction motors

Roadmaps, rail-lines, air-routes, ferries…

- If you want to catch the ferry, you need to be at the dock before it leaves.
- You need to understand how other roadmaps and timelines affect yours.

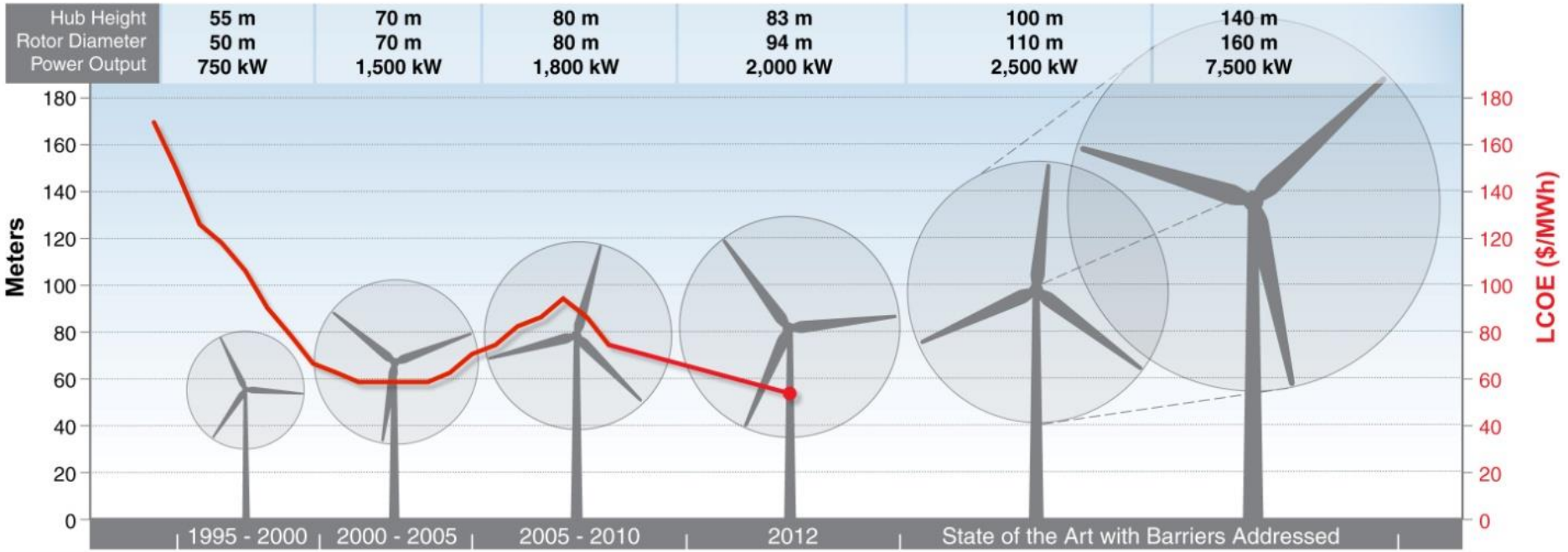
Industry Scale Roadmaps (and detours)

International Technology Roadmap for Semiconductors



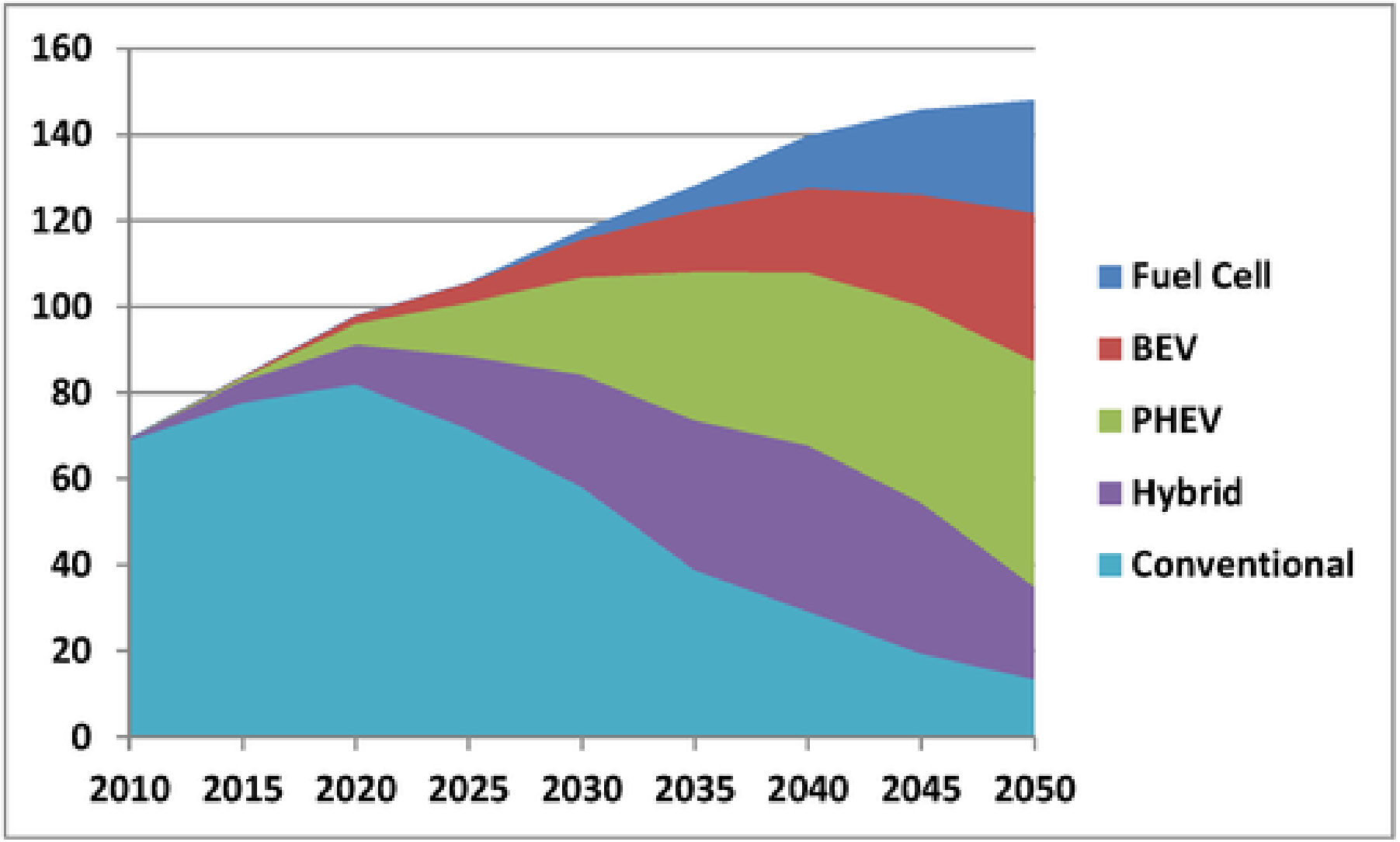
Source: *SEMATECH*

Wind turbine evolution



Source: *NREL Technical Report, NREL/TP-5000-61063, January 2014*

Automotive technology evolution



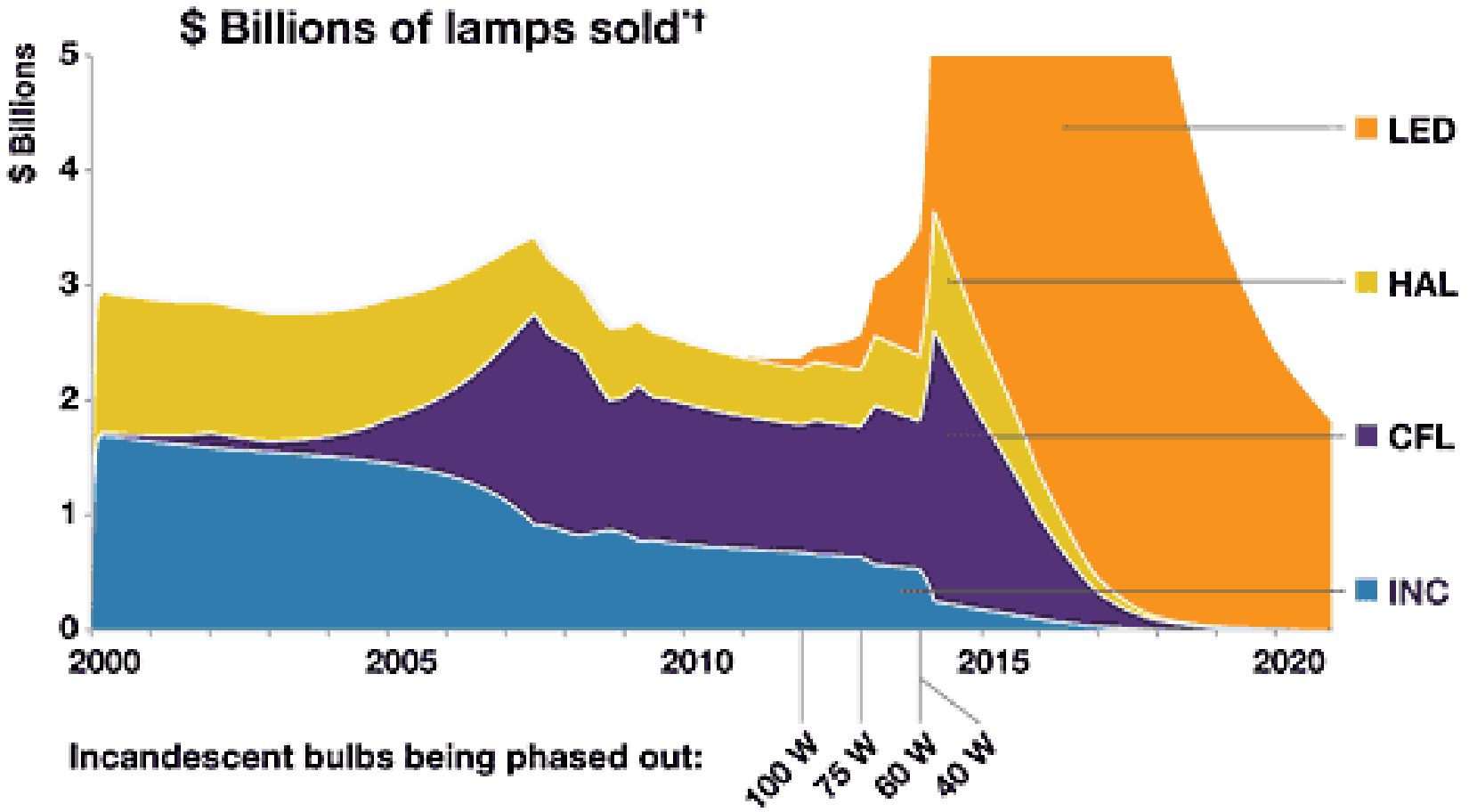
Fulton, Lah & Cuenot, *Sustainability* **5** (2013) 1863-1874
doi:10.3390/su5051863

Technology emergence
Case study: electric vehicles

Assumption: The market penetration of EVs will rise when a battery technology emerges that provides all-electric range close to that of a single tank of gasoline, if the price premium is similar to that of a hybrid.

- ~15,000,000 new cars are sold in the US every year.
- ~7% of new car sales in California are hybrids.
- Guess that the market for an all-electric vehicle could rise to 1,000,000 per year.
- If the battery requires 20kg of “unobtainium” the demand is around 20,000 tonnes, for US consumption alone. This is a small percentage of current world production for some elements, but a very large percentage for others.

Lighting evolution – *(dimmables only)*



Source: Lutron Corp *www.lutron.com*

Summary

- A journey of a thousand miles begins when you get out the map.
- Material choices influence technology choices (and vice versa), but only when new product generations emerge.
- If you miss the decision window, you lose.
- Make sure you don't miss the boat.
  - Be aware of others' milestones and decision points
  - Align your milestones with your users'
  - Reach the key decision points early

Thank You!

Questions?

https://cmi.ameslab.gov